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CONTRIBUTIONS OF SHORT-LIVED RADIOIODINES TO THYROID DOSES RECEIVED BY EVACUEES FROM THE CHERNOBYL AREA ESTIMATED USING EARLY *IN VIVO* ACTIVITY MEASUREMENTS

M. Balonov†*, G. Kaidanovsky†, I. Zvonova†, A. Kovtun‡, A. Bouville§, N. Luckyanov§ and P. Voillequé||
†Institute of Radiation Hygiene, St Petersburg, Russia
‡Institute of Industrial and Marine Medicine, St. Petersburg, Russia
§DHHS/NIH/NCI/Division of Cancer Epidemiology and Genetics, Bethesda, MD, USA
||MJP Risk Assessment, Inc., Denver, CO, USA

INVITED PAPER

Abstract — A series of *in vivo* gamma spectrometric measurements of 65 people evacuated from Pripyat 1.5 days after the Chernobyl Nuclear Power Plant Unit 4 explosion was performed in St Petersburg, Russia, as early as 30 April 1986. The historical spectra and interviews were recently processed and the results used for thyroid dose estimation. Activities of ^{131}I in thyroid and ^{132}Te in lungs were determined easily; for estimation of ^{132}I and ^{133}I activities in thyroid, sophisticated methods of spectral processing were developed. According to thyroid measurement data, the mean ratio of $^{133}I/^{131}I$ activities (at the time of the accident) inhaled by residents of Pripyat was 2.0. The mean ratio of thyroid dose from ^{133}I inhalation to that caused by ^{131}I amounts to 0.3, which confirms the accuracy of dose estimates based on the evolution of the Chernobyl accident. The mean ratio of ^{132}I activity in thyroid to that of ^{132}Te in lungs was assessed from the human measurement data to be 0.2, which is in reasonable agreement with the metabolic properties of these radionuclides. The mean ratio of thyroid dose from ^{132}I originating from ^{132}Te deposited in lungs to the dose caused by ^{131}I was 0.13 ± 0.02 for Pripyat residents who did not take KI pills and 0.9 ± 0.1 for persons who took KI pills. Thus, the contribution of short-lived radioiodines to total thyroid dose of Pripyat residents, which was on average 30% for persons who did not use stable iodine prophylaxis, and about 50% for persons who took KI pills on 26–27 April, should be accounted for in the assessment of thyroid health effects.

INTRODUCTION

In order to explain the unexpectedly high incidence of thyroid cancer in young inhabitants of the Chernobyl accident area, the United Nations Scientific Committee on the Effects of Atomic Radiation suggested assessing the contributions of radionuclides other than ^{131}I to thyroid dose and especially those of short-lived radioiodine(1). Higher radiobiological effectiveness of short-lived radioiodines because of the higher dose rates during thyroid irradiation was reported in early radiobiological studies on mammals(2).

In post-Chernobyl thyroid dose reconstruction studies, the contributions of short-lived radioiodines were modelled based on two kinds of input data: iodine and tellurium radionuclide inventories for the history of the reactor operation(1,3,4) and early environmental measurement data(1,5). In this paper we used an independent source of direct experimental data, namely a unique set of early *in vivo* measurement data, to assess thyroid doses.

About 200 people evacuated from Pripyat town on 27 April 1986, approximately 1.5 days after the Chernobyl Nuclear Power Plant Unit 4 explosion, arrived in St Petersburg, Russia as early as 28 April and applied for health inspection. They were hospitalised, decontaminated, monitored and interviewed by workers of the Institute of Radiation Hygiene and carefully investigated by physicians. A series of *in vivo* gamma spectrometric measurements of 65 people from this group was performed by workers of the Institute of Industrial and Marine Medicine (Dr A. Kovtun *et al*). For some of them (33 persons) a second series of measurements was performed 36–57 h later. In 2000–2001 the historical spectra and interviews were processed and the results were used for thyroid dose estimation.

MEASUREMENT TECHNIQUE

The measurements were performed from 30 April to 4 May 1986 with a portable scintillation spectrometer in three geometries: thyroid, lungs (Figure 1) and whole body (sitting position with upper body bent over the detector). For the thyroid and lung measurements, a collimated NaI(Tl) 40 × 40 mm detector with energy resolution of 6–7% for ^{137}Cs gamma radiation was used. Altogether in this study about 300 human measurement spectra were obtained and stored. The relevant personal information was obtained from interviews: identification data (name, age, gender, address), anatomical data (weight and height), characteristics of occupation in Pripyat before evacuation, conditions of evacuation, and

Contact author E-mail: m.balanov@iaea.org
*Present address: International Atomic Energy Agency, Wagramerstrasse, 5, PO Box 100, 1400, Vienna, Austria.

description of decontamination procedures, including stable iodine prophylaxis practices of 49 persons.

The energy-dependent calibration coefficients (kBq cps^{-1}), for thyroid and lung measurements were obtained by calculation accounting for measurement geometry, probability of photopeak registration of gamma quanta, and absorption of gamma radiation by human tissues. The estimated coefficients are given in Table 1. The calculation methodology was validated by measurement of a ^{137}Cs source placed at the human neck; the deviation of calculated calibration coefficients from one obtained from the measurements was less than 5%.

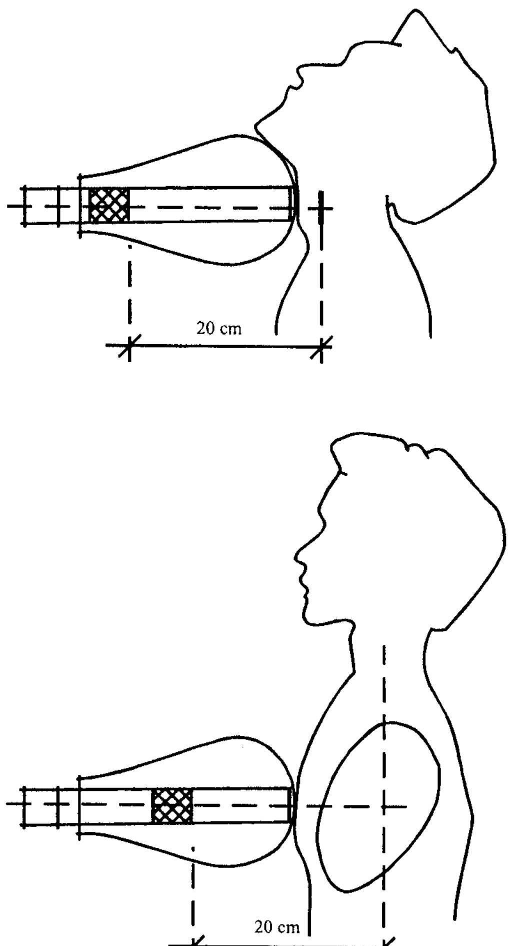

Figure 1. Geometry of measurements of radionuclides in thyroid (above) and in lungs (below).

Table 1. Calibration coefficients *K* (kBq cps^{-1}) for the radionuclides of interest and the measurement geometries.

Organ	^{132}Te (228 keV)	^{131}I (365 keV)	^{132}I (773 keV)	^{133}I (530 keV)
Thyroid	—	1.48	3.70	1.73
Lungs	1.59	1.97	4.90	2.30

The photopeaks of ^{131}I in thyroid and ^{132}Te in lungs were identified with confidence in the spectra of most measured persons and processed with a special computer code 'Aspect' developed at the International Institute of Nuclear Research, Dubna, Russia[5]. In contrast, photopeaks of ^{132}I (668 keV, 773 keV and others) and ^{133}I (530 keV) in thyroid were difficult to identify in the mixed spectra; therefore, special sophisticated methods of spectral processing were developed and applied.

The activity of ^{133}I in thyroid was determined from reduction of the count rate in the energy range of 500–560 keV according to ^{133}I decay with the half-life of 20.8 h, taking into account the change in contribution with time of gamma rays with higher energies to the count rate in that 60 keV window. This contribution was extrapolated from the energy range of 580–850 keV.

For detection of ^{132}I in thyroid, the most appropriate part of the spectrum was selected (723–881 keV). In addition to the gamma radiation of ^{132}I with energy 773 keV, at least the following fission radionuclides contained in thyroid or nearby soft tissues contribute: ^{134}Cs (796 keV), ^{136}Cs (819 keV), the Compton part of the spectra of ^{132}I (955 keV) and ^{136}Cs (1048 and 1235 keV) as well as the right 'tail' of the non-resolved group of photopeaks of ^{131}I (637 keV), ^{137}Cs (662 keV) and ^{132}I (630 and 668 keV). The count rate of the ^{132}I photopeak of 773 keV was calculated from an equation system with the count rates in energy ranges 567–700 keV (radiation of ^{137}Cs (662 keV), ^{134}Cs (50% of 563 + 569 keV peaks and 92% of 605 keV peak), ^{131}I (637 keV) and ^{132}I (668 keV)) and 723–881 keV (^{134}Cs (796 keV), ^{136}Cs (818.5 keV) and ^{132}I (773 keV)) as well as the statistically confident count rate of ^{131}I as input data. The ratios of caesium radioisotopes in the Chernobyl fallout were assumed to be $^{137}Cs : {}^{134}Cs : {}^{136}Cs$ = 1.0 : 0.58 : 0.23[1,6], and the values of quantum yields for all indicated gamma radiation lines were taken from ICRP Publication 38[7].

Uncertainties of the activities of ^{131}I, ^{132}I and ^{133}I in thyroid and ^{132}Te in lungs were estimated taking into account statistical uncertainties of count rates in all the energy ranges involved; uncertainties of the radiation quantum yields and in the calibration coefficients were not accounted for. Applied methods of spectral processing are given in more detail in Balonov *et al*[8] along with the data from another independent series of early *in vivo* counting of the same patients. Average ^{131}I and ^{132}I activity estimations for the same group agreed within factor of 1.5 for both radionuclides.

MEASUREMENT RESULTS AND DISCUSSION

Iodine-131 in thyroid

The activities of ^{131}I in thyroid were statistically significant in 59 of 62 investigated persons with available thyroid spectra. The relative uncertainty (ratio of the standard error to the activity value) of these results was generally less than 30%. In three persons ^{131}I activities were below the minimum detectable activity (MDA), which ranged from 1 to 3 kBq for these individuals. The range of activities measured at 155–230 h after the reactor explosion was between <1 kBq and 244 kBq. In 33 persons of all age groups with repeated measurements the ^{131}I thyroid activity declined with an average half-time of 5.2 ± 0.4 days.

Comparison of ^{131}I thyroid activities in adults with different behaviour during 26–27 April in Pripyat has revealed a significant influence of both time spent outdoors and taking stable iodine preparations. Based on available measurement data, summarised in Table 2, the effectiveness of thyroid blocking was estimated to be a factor of 7 ± 2. The dose reduction achieved by staying mainly indoors was a factor of about 2.0 ± 0.6. A combination of these simple countermeasures reduced the mean ^{131}I thyroid activity and associated dose by more an order of magnitude.

Iodine-133 in thyroid

The ^{133}I activity was determined in 33 persons with repeated thyroid measurements. In six of these persons statistically significant (95% confidence level) activities of ^{133}I in the range from 1.3 to 5.2 kBq were observed. These were persons who stayed mainly outdoors and did not take stable iodine, or took it late. Also important was the fact that they were measured earlier, 135–155 h after the accident. For the other 27 persons, ^{133}I activities were below appropriate MDAs (0.6 to 4 kBq for different persons) with a confidence level of 95%. In the latter case a one-sided criterion was applied.

For 22 persons with reliable measurement statistics of both ^{131}I and ^{133}I, the activity ratio F, decay corrected to the time of the reactor explosion, was calculated as follows:

$$F = G_{133}(t_{m1})/G_{131}(t_{m1}) \exp[\lambda_{133} - \lambda_{131})t_{m1}], \qquad (1)$$

where $G_{133}(t_{m1})$ and $G_{131}(t_{m1})$ (in Bq) are thyroid activities of ^{133}I and ^{131}I, correspondingly, at the moment of the first measurement t_{m1} and λ_{133} and λ_{131}, (h^{-1}) are decay constants of ^{133}I and ^{131}I equal to 0.033 h^{-1} and 0.0036 h^{-1} respectively[7]. Equation 1 is dimensionless.

The mean value of F was estimated to be equal to 2.0 with a standard deviation of individual data of 1.9 and upper 95% (one-sided criterion) value of 5.4. This is in a reasonable agreement with the value of 1.5 known from nuclear calculations of the radionuclide inventory performed for the RBMK-1000 type reactor and campaign time of 1100 days[9], which is very close to conditions of the Chernobyl Nuclear Power Plant Unit 4 at the time of the accident. From the estimated radionuclide release from the destroyed reactor[1], the following range of ^{133}I to ^{131}I ratios can be assessed: 1.5 to 2.1. These updated release assessments also agree well with our estimate of 2.0 based on early human thyroid activity measurements.

Table 2. Mean ^{131}I thyroid activity in adult inhabitants of Pripyat (kBq, decay and excretion corrected to 12 noon on 4 May 1986) depending on time spent outdoors occupation in open air and taking KI pills*.

Took KI pills on 26–27 April 1986	Mainly indoors on 26–27 April 1986	Long time in open air on 26–27 April 1986
Yes	10 ± 2 (19)	197 ± 5 (13)
No	647 ± 8 (4)	133 ± 32 (9)

*Mean ± standard error; number of subjects shown in parentheses.

Tellurium-132 in lungs

The activities of ^{132}Te in lungs were statistically significant in 56 persons; in 8 persons ^{132}Te activities were below MDAs (0.4–0.8 kBq) for different persons. The range of activities was from less than 0.4 kBq to 73 kBq. In 28 persons of all age groups with repeated lung measurements the ^{132}Te activity in the lungs declined with an average half-time of 2.5 ± 0.2 days. No statistically significant dependence of mean ^{132}Te lung activity on occupation in the open air was revealed.

Iodine-132 in thyroid

The ^{132}I activity was determined in 52 persons. In 32 persons the activity of ^{132}I was statistically significant with the confidence level 95%; for the other 20 persons, ^{132}I activities were below appropriate MDAs (1–6 kBq) for different persons, again determined using a confidence level of 95% and a one-sided criterion. The range of activities was from less than 1 kBq up to 17 kBq. The average ratio of interconnected activities ^{132}I in thyroid to ^{132}Te in lungs was estimated to be 0.20 ± 0.03 with a standard deviation of 0.14 and individual value range of 0.07 to 0.6.

ALGORITHM FOR THYROID DOSE ESTIMATION

As most of the Pripyat inhabitants, 62% according to Goulko *et al*[10] and 75% of the group studied in the present work, took stable iodine on 26–27 April, the assessment of thyroid dose D_k (in mGy) of the inhaled

kth iodine radioisotope should take into account the associated effect of thyroid blocking:

$$D_k(A) = d_k(A) \int_0^{t_e} i_k(t,A)\, b(t - t_b)\, dt, \qquad (2)$$

where $d_k(A)$ (mGy kBq^{-1}) is the ICRP dose coefficient for inhalation of the kth iodine radioisotope by a person of age A[11]; $i_k(t,A)$ (kBq h^{-1}) is the intake rate for the kth iodine isotope in the body of a person of age A; t_e (h), is the time from the moment of the accident until the time of evacuation; as a rule, it is 36 to 39 h; $b(t)$ (dimensionless) is thyroid blocking factor (see below); t_b (h) is the time of taking stable iodine.

The intake rate is proportional to the kth radionuclide concentration in the town air, $C_k(t)$ (kBq m^{-3}) and to the breathing rate of a person of age A, $V(t,A)$ (m^3 h^{-1}):

$$\begin{aligned} i_k(t,A) &= C_k(t)\, V(t,A) \\ &= i_k(0,A)\, c_k(t)\, v(t,A) \\ &= i_k(0,A)\, \varphi_k(t,A)\ (\text{kBq h}^{-1}), \end{aligned} \qquad (3)$$

where $i_k(0,A)$ (kBq h^{-1}) is the initial inhalation rate of the kth radionuclide by a person of age A (being awake); $c_k(t)$ and $v(t,A)$ (dimensionless) are relative air concentration of the kth radionuclide and relative breathing rate, respectively; $\varphi_k(t,A) = c_k(t)\, v(t,A)$ (dimensionless) is the relative inhalation rate of the kth radionuclide by a person of age A.

Whereas early air concentration data for Pripyat are very scarce, we assumed, as the first approximation, that air concentration of the mixture of radionuclides and, in particular, ^{131}I concentration, is linearly related to the air dose rate. According to published data[12], the dose rates in air at locations in Pripyat town were approximately constant during the first 12–20 h after Unit 4 exploded at 1 a.m. on 26 April. Then the dose rate increased due to a change in wind direction and continuing radionuclide release. This dose rate increased during the entire period before evacuation of the population (2 to 5 p.m. on 27 April). The dynamics of the air dose rate and associated ^{131}I concentration can be approximated, according to plots presented by Likhtarev *et al*[12], by linear functions with the following mean relative parameters:

$$\begin{aligned} c_{131}(t) &= 1, && \text{for } 0 < t \le t_2, \\ c_{131}(t) &= 1 + 1.3\,(t - t_2) && \text{for } t > t_2, \end{aligned} \qquad (4)$$

where $t_2 \approx 15$ h after the accident is the mean time when the air dose rate started to increase.

The dynamics of the activity intake in the body are also influenced by the rate of lung ventilation, which depends on the age and activity of the individual. For the purposes of this paper, we distinguish between the states of being awake with light exercise and of night sleep. According to ICRP 71[11], for adults and children above the age of 10 the breathing rate at night is lower by about a factor of 3; this ratio was accepted for modelling inhalation rate (see Table 3).

To model radioiodine inhalation, we established five time intervals which were determined by the dynamics of radionuclide concentrations in air and by the behaviour of people (periods of sleep and being awake, and eventual evacuation). For individual thyroid dose calculations, periods of sleeping and of being awake were specified from the person's interview. When individual interviews were missing, the default average parameters from Table 3 were used. For those ingesting stable iodine pills, additional time intervals were introduced, which started from the moment of the pill taking, t_b.

The parameters from Table 3 were used in Equation 3 in order to model dynamics of ^{131}I inhalation intakes. To account for decay of shorter-lived radionuclides, Equation 3 was multiplied by an appropriate time-dependent exponential decay function.

It is believed that taking stable iodine preparations, usually KI pills, prevents incorporation of radioiodine in thyroglobulin for some time and thus reduces the thyroid dose caused by retention of organically bound radionuclides[13–16]. The value and time dependence of the thyroid blocking factor $b(t)$ applicable in Equation 2 to organically bound radioiodine in the case of ingestion regular dosage of 100 mg of iodide (130 mg of KI) at time moment t_b was obtained by processing human observation data[14] and appropriate modelling:

$$\begin{aligned} b(t) &= 0.03 + 0.97 \\ &\{1 - \exp[-0.12\,(t_b - t)]\} \text{ for } t < t_b, \\ b(t) &= \frac{1.06 - \exp[-0.03\,(t - t_b)]}{1.06 + \exp[-0.03(t - t_b)]} \quad \text{for } t \ge t_b, \end{aligned} \qquad (5)$$

where 0.03, 0.97 and 1.06 are dimensionless and 0.12 (h^{-1}) and 0.03 (h^{-1}) are parameters of functions which approximate the time-dependent thyroid blocking factor[13–15].

According to the assumed model for inhalation of iodine radioisotopes in the human body, we calculate their uptake and retention in thyroid by the moment t_m, when activity $G_k(t_m)$ of ^{131}I or ^{133}I is measured in thyroid. Then, the unknown parameter $i_k(0,A)$ (kBq h^{-1}) of the intake function is determined from the equation

$$i_k(0,A) = G_k(t_m) \exp(\ln 2\; t_m/T_k) \Big/ \left(\epsilon_h \int_0^{t_e} \varphi_{131}(t,A) \exp(\ln 2\; t/T_{131})\, b(t - t_b)\, R(t_m - t,A)\, dt\right), \qquad (6)$$

where, $G_k(t_m)$ (kBq) is measured ^{131}I or ^{133}I activity in thyroid as of the moment t_m (h); $\varphi_{131}(t,A)$ (dimensionless) is the ^{131}I intake function, see Equation 3 and Table 3; T_k (h), is half-life of the kth iodine radioisotope; $b(t)$ (dimensionless) is the thyroid blocking factor, see Equation 5; ϵ_h (dimensionless) is the fraction of the radionuclide absorbed in blood as a result of inhalation — for the mixture of equal radioiodine air concentrations of elemental iodine, methyliodide and aerosols with AMAD of 1 μm and fast absorption in the inhalation tract, $\epsilon_h = 0.66$[11]; $R(t,A) = 0.3 \exp[-\ln 2\, t/T(A)]$ (dimensionless) is the iodine retention function in thyroid where $T(A)$ is the age-dependent biological half-time[17].

Once the $i_k(0,A)$ value is determined from Equation 6, the thyroid dose can be calculated according to Equation 2 using individual occupation data and corresponding dose coefficients for inhalation of ^{131}I or ^{133}I, respectively[11].

With regard to ^{132}I thyroid dose, in this paper we consider only its major component, i.e. the component caused by ^{132}I originating from ^{132}Te deposited in the lungs. According to our data this component contributes on average more than 95% to the total thyroid dose caused by ^{132}I. The remaining ^{132}I thyroid dose (on average, less than 5%) was caused by immediately inhaled ^{132}I, both released from the destroyed reactor and built-up in air from the released ^{132}Te.

It is further assumed that regularities of ^{132}Te inhalation by the Pripyat inhabitants are similar to regularities of ^{131}I inhalation rate with account for radioactive decay. Then, time- and age-dependent ^{132}Te lung deposition rate $l_{Te}(t, A)$ (in kBq h^{-1}) can be modelled as follows:

$$l_{Te}(t,A) = l_{Te}(0,A)\, \varphi_{131}(t) \exp[-\ln 2\, t(1/T_{1/2.Te} - 1/T_{131})], \tag{7}$$

where $T_{1/2.Te}$ is the half-life of ^{132}Te equal 78 h[7].

In a similar way to Equation 6 and taking into account Equation 7, the unknown parameter $l_{Te}(0,A)$ (kBq h^{-1}) of the ^{132}Te lung deposition rate function can be determined from the lung measurement data by the equation:

$$l_{Te}(0,A) = L_{Te}(t_m) \left(\int_0^{t_c} \varphi_{131}(t) \exp[-\ln 2\, t(1/T_{1/2.Te} - 1/T_{131})] R_{Te}(t_m - t)\, dt \right)^{-1}, \tag{8}$$

where $L_{Te}(t_m)$ (kBq) is ^{132}Te activity in lungs at the measurement moment t_m (h); $R_{Te}(t) = \exp(-\ln 2\, t/T_{Te})$ (dimensionless) is ^{132}Te retention function in lungs; the mean half-time of ^{132}Te in lungs, T_{Te}, is equal to 2.5 ± 0.2 d or 60 ± 5 h independent of a person's age (see above).

Once the $l_{Te}(0,A)$ value is determined from the lung measurement data by Equation 8, the ^{132}Te activity in lungs (in kBq) can be calculated by integral convolution using individual occupation data as follows:

$$L_{Te}(t) = l_{Te}(0) \int_0^t \varphi_{131}(\tau) \exp[-\ln 2\, \tau(1/T_{1/2.Te} - 1/T_{131})]\, R_{Te}(t - \tau)\, d\tau. \tag{9}$$

Not considering, for simplicity, the effect of thyroid blocking with stable iodine on dose caused by incorporated ^{132}I and taking into account our measurement data as above, time-dependent ^{132}I activity in thyroid (in kBq) can be simply estimated as being proportional to ^{132}Te activity in lungs:

$$G_{132}(t) \approx 0.2 L_{Te}(t) \tag{10}$$

Based on Equations 9 and 10, the thyroid dose caused by ^{132}I radiation (in mGy) can be calculated as follows:

$$D_{132} = 0.576\, \mathrm{SEE}_{132}(A) \int_0^\infty G_{132}(t)\, dt = 0.115\, \mathrm{SEE}_{132}(A) \int_0^\infty L_{Te}(t)\, dt, \tag{11}$$

where 0.576 is the numeric coefficient that converts MeV to joules, Gy to mGy, Bq to kBq and seconds to hours; and $\mathrm{SEE}_{132}(A)$ (in MeV (g decay)$^{-1}$) is the specific effective energy of ^{132}I radiaton for persons of age A (in years)[11,17].

Equation 11 is used when ^{132}Te activity in lungs $L_{Te}(t_m)$ has been measured; when ^{132}I activity in thyroid, $G_{132}(t_m)$, is available, Equation 11 can be applied with a condition that $L_{Te}(t) = G_{132}(t)/0.2$.

Table 3. The model parameters for inhalation rate of iodine radionuclides.

Time interval number	Time interval (default) (h)	Relative breathing rate $v(t)$ (default)	Relative air concentration $c_{131}(t)$	Comments
1	0–7	0.3	1	Period of sleeping, stable concentration in air
2	7–15	1	1	Period of being awake, stable concentration in air
3	15–22	1	$1 + 1.3(t - 15)$	Period of being awake, growing air concentration
4	22–30	0.3	$1 + 1.3\,(t - 15)$	Period of sleeping, growing air concentration
5	30–39	1	$1 + 1.3\,(t - 15)$	Being awake, growing air concentration, evacuation

THYROID DOSE ASSESSMENT AND DISCUSSION

The values of doses from ^{131}I calculated for 62 Pripyat inhabitants according to Equations 2 to 6 vary from 6 to 904 mGy; the average was 110 ± 16 mGy. In 16 children from 4 to 17 years of age, the average dose was 90 ± 20 mGy; in 46 adults it was 120 ± 20 mGy. The difference between age groups is not significant, but to some extent reflects the differences in breathing rates and thyroid masses for children and adults.

Like ^{131}I thyroid activities (see Table 2), the doses received strongly depend on human behaviour at the time after the accident. Taking stable iodine preparations decreased the average inhalation dose by a factor of about seven. The earliest ingestion of stable iodine pills was reported to be 6–7 h after the accident. Staying indoors most of the time reduced the dose by a factor of about 2 as compared with staying outdoors. Combination of these two countermeasures resulted in thyroid dose reduction by more than an order of magnitude.

In comparison with the data of Gulko *et al*[10] based on an analysis of about 200 ^{131}I thyroid measurements of the Pripyat residents and about 10,000 interviews on their behaviour after the accident, present estimations of the mean thyroid dose in adults caused by inhalation of ^{131}I are higher by a factor of two. According to Gulko *et al*[10], residence of people in different areas of the Pripyat town significantly influenced thyroid dose. Thus, for a more detailed comparative analysis of two data sets, the residence location should be accounted for.

Doses calculated according to Equations 2 to 6 from the results of ^{133}I measurements in thyroids of Pripyat inhabitants range from less than 5 mGy up to 170 mGy. For 22 persons with reliable measurement statistics, the average ratio of the dose from ^{133}I to the dose from ^{131}I was 0.3 with a standard deviation of 0.5. This average ratio obtained from measurement data of 8 persons who did not take KI pills was estimated to be 0.11 with a standard deviation of 0.07, compared with 0.6 with a standard deviation of 0.6 in 14 persons who took KI pills. The difference between the two latter values is statistically insignificant. The dose contribution of ^{133}I is much lower than the ratio of the released activity of ^{133}I to that of ^{131}I (1.5 to 2, see above) not only because the dose coefficient for ^{133}I is lower by a factor of 5 to 6 than that of ^{131}I[11] but also because most inhalation of radioiodines by Pripyat inhabitants occurred on 27 April 1986, when radioactive decay had significantly decreased the activity of ^{133}I.

The ^{132}I thyroid dose was calculated according to Equations 7 to 11 for 64 persons, including 32 persons with statistically significant measured ^{132}I thyroid activity and 32 other persons for whom dose estimations were based on ^{132}Te lung measurements. The doses range between less than 1 mGy and 240 mGy. In 17 persons who did not take KI pills the mean ratio of the ^{132}I dose to ^{131}I dose was 0.13 ± 0.02 with a maximum value of 0.4 and standard deviation 0.09. In 42 persons who took KI pills this ratio was 0.9 ± 0.1 with a maximum value of 3.2 and standard deviation 0.7. This statistically significant difference is explained mainly by the fact that ^{132}I originating from ^{132}Te deposited in lungs enters the bloodstream continuously, including the time period when the effect of a single stable iodine intake has diminished.

The analysis of the early *in vivo* counting data of Pripyat residents who inhaled radioiodines during about 1.5 days prior to evacuation from the Chernobyl accident area has revealed that there was a substantial contribution of short-lived radioiodines to the thyroid dose. Thus, in persons who did not use stable iodine prophylaxis the mean contribution of ^{132}I to thyroid dose is estimated to be about 9% [0.13/(1.0 + 0.13 + 0.3) = 0.09] and that of ^{133}I about 21% [0.3/(1.0 + 0.13 + 0.3) = 0.21]. In total about 30% of internal thyroid dose to persons not taking KI came from short-lived radioiodines.

For persons who took KI pills on 26–27 April, this contribution is significantly higher, e.g. about 40% [0.9/(1.0 + 0.9 + 0.3) = 0.41] from ^{132}I and about 14% from ^{133}I. Thus, more than half of the internal thyroid dose originated from short-lived radioiodines. One should note, however, that in this group stable iodine prophylaxis reduced the committed thyroid dose from ^{131}I by an order of magnitude and total thyroid dose from ^{131}I, ^{132}I and ^{133}I by a factor of about five compared with other Pripyat residents.

These peculiarities of thyroid exposure of about 50,000 Pripyat residents should be recognised when forecasting health effects of the Chernobyl accident in the local population and/or analysing epidemiological data relevant to thyroid pathologies. The results of the present work could also be used in order to assess the contribution of short-lived radioiodine to the thyroid dose of other evacuated population groups and of permanent residents of areas contaminated as a result of the Chernobyl accident.

CONCLUSION

1. According to thyroid measurement data, the mean ratio of $^{133}I/^{131}I$ activities (at the time of the accident) inhaled by residents of Pripyat town was 2.0 with a standard deviation of individual data of 1.9. This is in a good agreement with other estimations of this ratio based on estimates of radioiodine releases from the Chernobyl accident.
2. The mean ratio of thyroid dose from ^{133}I inhalation to that caused by ^{131}I in Pripyat residents evacuated from the accident area 1.5 days after the reactor explosion was 0.3, with a standard deviation of 0.5, which confirms the accuracy of dose estimates based on estimates of radioiodine releases from the Chernobyl accident.

3. The mean ratio of ^{132}I activity in thyroid to that of ^{132}Te in lungs was assessed from the human measurement data to be 0.2 with a standard deviation of 0.14, which is in a reasonable agreement with the known metabolic properties of these radionuclides.
4. The mean ratio of thyroid dose from ^{132}I originating from ^{132}Te deposited in lungs to the dose caused by ^{131}I was 0.13 ± 0.02 for Pripyat residents who did not take KI pills and 0.9 ± 0.1 in persons who took KI pills.
5. Thus, the contribution of short-lived radioiodines to the internal thyroid doses of Pripyat residents, about 30% for persons who did not use stable iodine prophylaxis and about 50% for persons who took KI pills on 26–27 April, should be accounted for in assessments of thyroid health effects.

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